



## AURORAL ZONE PLASMA WAVES DETECTED AT POLAR: PCBL WAVES

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### ABSTRACT

Polar Cap Boundary Layer waves are ELF/VLF electric and magnetic waves detected on field lines adjacent to the polar cap, thus their name. Waves are present at this location 96% of the time. The wave latitude-local time distribution is shown to be the same as that of the auroral oval. The most intense waves are detected coincident with the strongest magnetic field gradients (field-aligned currents). Specific frequency bands of whistler mode-waves are identified: ~200 Hz, 1-2 kHz and ~5 kHz. Two types of intense electric waves are present: solitary bipolar pulses (electron holes) and ~kHz electric turbulence. The PCBL waves are most likely a consequence of auroral zone field-aligned current instabilities. The currents have in turn been ascribed to be due to magnetospheric convection driven by the solar wind.

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### INTRODUCTION

Low latitude (magnetopause) boundary layer (LLBL) ELF-VLF plasma waves have been studied by a variety of spacecraft missions (Gurnett et al., 1979; Tsurutani et al., 1981, 1989; Gendrin, 1983), both at Earth and Jupiter (Tsurutani et al., 1993, 1997). The waves as detected by spectral analyses were noted to be "broadband" in electric ( $E$ ) and magnetic ( $B$ ) signatures. Because the  $B/E$  amplitude ratio did not fit that for a pure whistler mode, it was suggested that the waves were a superposition of electromagnetic whistler mode waves plus electrostatic signals (Gurnett et al., 1979; Tsurutani et al., 1989; 1997). Recent analysis of POLAR plasma wave data (Tsurutani et al., 1998a, 2000) have indicated that broadband waves with similar properties exist at lower altitudes on field lines bounding the polar cap (thus called Polar Cap Boundary Layer waves). It is speculated that these waves are on LLBL magnetic field lines, but at lower altitudes. POLAR high-time resolution data have resolved the cause of the "broadbandedness" of the PCBL waves (Franz et al., 1998; Tsurutani et al., 1998b). There are indeed whistler mode emissions present, but the waves are patchy packets lasting only ~10 ms duration. The packets occur with a variety of frequencies, and integrated over time, a rough power law power spectrum is formed. Superposed with the whistler mode emissions are electric solitary waves with ~ms durations (Franz et al., 1998; Tsurutani et al., 1998b; see Lakhina and Tsurutani, 1999a, for a review). The latter electric phenomena are speculated to be electron holes (Franz et al. 1998; a general discussion of electron holes can be found in Muschietti et al., 1999).

It is the purpose of this paper to report the results of several statistical studies and high-time resolution data analyses of the POLAR PCBL waves. First, we use one-year of POLAR plasma wave data to determine the latitudinal location of the PCBL waves over a full 24 hours of local time. It will be shown that the latitudinal distribution is similar to that of the auroral oval. In summary, we will comment on the possible role that the PCBL/LLBL/auroral plasma waves are playing in the overall magnetospheric physics.

### RESULTS

The detection of the  $E$  waves is indicated in Figure 1. The distribution in the northern hemisphere corresponds to the near-apogee waves and that in the southern hemisphere, the near-perigee waves. Waves

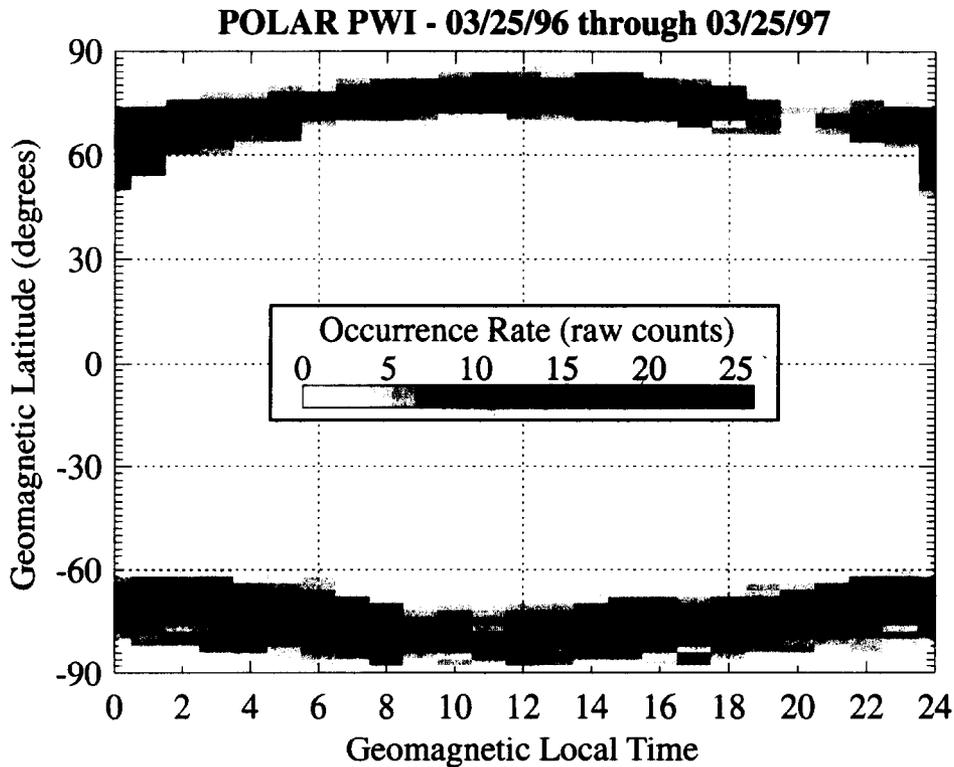


Fig. 1. The latitude-local time dependence of PCBL waves. On top are the near-apogee events and the bottom are the near-perigee events. The location of the waves is essentially the same as the auroral oval. The waves are detected at  $\sim 65^\circ$  magnetic latitude near midnight and at  $\sim 75^\circ$  near local noon.

were detected in 96% of the crossings. The waves are essentially a permanent feature of this latitudinal region, both near apogee and near perigee.

There are several important features in these latitude-local time distributions. First, the longitudinal locations (both north and south) of the waves are continuous, forming "rings" around the two magnetic poles of the Earth. The second important feature to note is that the shape and locations are quite similar to the Feldstein and Starkov (1970) auroral oval. The waves are found at higher magnetic latitudes ( $\sim 75^\circ$ ) near local noon, than at local midnight ( $\sim 65^\circ$ ), essentially the same as for the auroral oval.

### Waveform Data Results

On 20 May 1996, several "turnons" of the electric waves were detected. These events occurred at  $\sim$ noon local time at a magnetic latitude of  $77^\circ$  North.  $K_p$  was 1.0. An example at  $\sim 0825:55$  UT is shown in Figure 2. At 0825:54.581 UT, the  $E_{\parallel}$  signals appear out of background to reach  $\pm 1$  mV/m intensities by 0825:54.584 UT. There is little or no  $E_{\perp}$  component in these signals. The frequency of the signals is highest at the beginning of the event and becomes lower with increasing time. There is no detectable magnetic component accompanying the signals.

### Summary of Local Time Survey (Not Shown)

#### $\sim 200$ Hz Electromagnetic Waves

Low frequency  $\sim 200$  Hz electromagnetic waves were detected in all four local time sectors. Peak amplitudes were  $\sim \pm 1$  to  $2 \times 10^{-2}$  nT.

#### Bipolar Pulses, Offset Bipolar Pulses, and Monopolar Pulses

Isolated bipolar pulses and offset bipolar pulses (and monopolar pulses) were detected in all local time sectors except for dusk (however there was limited sampling). In the midnight sector, the amplitudes reached amplitudes of  $\pm 2$  mV/m.

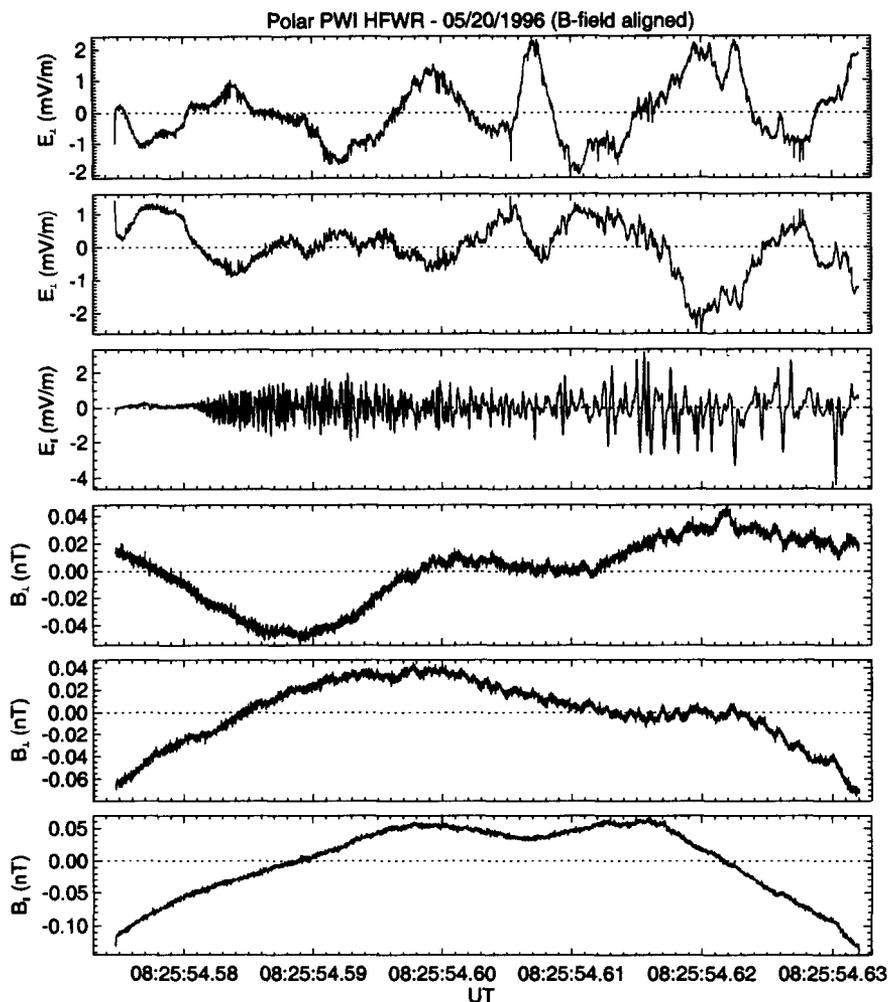


Fig. 2. The "onset" of a bipolar pulse event near local noon.

### ~ 1-2 kHz Electromagnetic Waves

1-2 kHz electromagnetic ( $B$ ) waves with amplitudes of  $\pm 5 \times 10^{-3}$  nT were detected at dawn.

### Electric Turbulence

Strong broadband electric turbulence ( $3 \times 10^2$  to  $6 \times 10^3$  Hz) was detected at all local times. The transverse  $E_{\perp}$  power is  $\sim 3 \times 10^{-4}$  mV<sup>2</sup> m<sup>-2</sup> Hz<sup>-1</sup> at  $10^3$  Hz and  $\sim 10^{-4}$  mV<sup>2</sup> m<sup>-2</sup> Hz<sup>-1</sup> at  $6 \times 10^3$  Hz. No obvious accompanying magnetic component was detected. Such waves were not detected in the absence of other fluctuations, however. If the electron plasma frequency determination is correct, these waves are at frequencies well below the electron plasma frequency.

### **DISCUSSION**

The PCBL waves were shown to have latitude dependences similar to that of the auroral oval. The wave amplitudes are most intense where there are strong magnetic field gradients (not shown). The nature of the  $E$  and  $B$  waves are quite similar to those detected at lower altitudes by experiments on Viking, Freja and FAST (Böstrom et al., 1988; Pottelette et al., 1990; Dubouloz et al., 1991; Ergun et al., 1999). Thus one obvious conclusion is that the PCBL waves are on auroral zone magnetic field lines. These same magnetic field lines map into the LLBL region of the magnetosphere at higher altitudes.

The apogee wave intensities are somewhat lower than observed near the ionosphere (Polar perigee events). However the decrease with altitude is not commensurate with a simple dependence on wave spreading

with magnetic field line divergence. The wave decrease is much less than such a mechanism could account for (Tsurutani et al. 1998a). The observations of bipolar pulses (nondispersed solitary waves) and offset bipolar pulses and monopolar pulses (dispersed solitary waves) at POLAR near-apogee altitudes leads to the argument that POLAR is detecting both freshly created waves and also evolved waves/structures, i.e., there is a mixture of sources (local and nonlocal) along the field lines.

### FINAL COMMENTS

It is apparent that the PCBL waves are global, auroral phenomena. Their generation is most likely related to near-ionosphere particle acceleration with further particle beaming as the particles are adiabatically decompressed as they propagate to higher altitude, lower ambient magnetic field regions. These field-aligned particles are also believed to carry a part of the field-aligned currents associated with the polar cap/magnetospheric convection processes (Carlson et al., 1998). Thus from this scenario, the particle beams, plasma waves and field-aligned currents are all intimately related. The free energy available in the field-aligned currents and gradients in the currents, plasma density and magnetic field can drive several plasma instabilities that can lead to the observance of broadband plasma waves (Lakhina and Tsurutani, 1999b). This local growth of waves at all altitudes should occur if this picture is a correct one.

The noontime waves have been shown to be more intense under magnetic field reconnection conditions ( $B_z < 0$ ). This has been found for both the PCBL waves (not shown here, see Tsurutani et al., 2000) and for LLBL waves (Tsurutani et al., 1989). Enhanced magnetic reconnection will lead to stronger polar/magnetospheric convection and greater field-aligned currents (a natural consequence), and hence greater wave amplitudes. Similar statements can be made for the near-midnight waves. Stronger nightside magnetic reconnection during substorms and storms will lead to the strongest field-aligned current system, and thus the greatest wave amplitudes (as was detected, Tsurutani et al., 2000).

The continuous presence of the PCBL/LLBL/auroral zone waves indicate that charged particles will not be confined to their field lines, but will be able to diffuse into other regions of space (Tsurutani and Thorne, 1982). Cross-field diffusion of magnetosheath plasma onto closed LLBL field lines and trapped magnetospheric plasma out into the magnetosheath can be accomplished by resonant interaction with these waves.

These global auroral processes should occur at all planets where there is a strong interaction between the solar wind and the magnetosphere. Boundary layer physics at Jupiter and Saturn will be studied in the near future to determine the similarities and differences to the Earth's case.

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